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FINAL ENGINEERING REPORT

JPL LETTER CONTRACT L—47192

NAS 7-100

23 Pages of Text Plus
23 Pages of Appendices

Prepared by:

ITTL Avionics Laboratory
San Fernando, California

Approved by:

C. T. Clark
Assoc. Lab Director

I T T L A B O R A T O R I E S
A Division of International Telephone & Telegraph Corporation
15151 Bledsoe Street San Fernando, California

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I. ABSTRACT

JPL contract L-47192 with ITT Laboratories provided for design, fabrication, assembly and test support to JPL in the supply of nine Vega Reference Units and four Laboratory Test Equipment units. Basic platform design is adapted from that employed in the Sergeant.

Scheduled delivery of the first units was mid-February 1960. Due to cancellation of the Vega program in December 1959, only partial completion of the first platform was achieved. All residual material, including both purchased and fabricated items has been transferred to JPL. Complete documentation in the form of vellum drawings has been turned over to JPL.

This report details the status of the several technical areas of the project at the time of cancellation.

II. INTRODUCTION

A. Background and Purpose

Jet Propulsion Laboratory Contract L-47192 was negotiated with ITT Laboratories to provide JPL with engineering, design, fabrication, and testing support in the supply of inertial reference units (VRU's) for the Vega space vehicle. Specifically, ITTL was required to furnish the necessary personnel and facilities to fabricate, assemble, wire, and test nine inertial platform systems of JPL design. ITTL effort included:

1. An evaluation of the JPL mechanical and electronic design including a study of tolerances, producibility, thermal characteristics, reliability, adequacy of associated tooling, etc.

2. The establishment of bills of material and schedules for the release of this material for procurement and fabrication to meet the required delivery schedules.

3. The release of material for procurement and fabrication as required in the actual assembly and test of VRU equipments.

4. The changing or re-drafting of any JPL drawings as needed and the provision of all other drawings deemed necessary for fabrication, procurement, inspection, assembly, wiring, and testing of equipments.

5. The utilization and modification, if necessary, of mutually agreed upon fixtures, tooling, and test equipment available from JPL.

6. The fabrication or procurement of all additional equipment needed to accomplish the project as specified.

Under the terms of the contract, JPL and ITTL maintained extremely close technical liaison in order to facilitate to the greatest possible extent the accomplishment of project aims within the prescribed schedule.

To this end, engineering meetings were held at either ITTL or JPL on a regular weekly basis or more often as required.

B. Schedule

The procurement and testing of the gyros and accelerometers was handled by JPL. The release of these components for installation in the platform was arranged to mesh with the ITTL fabrication and assembly schedules such that finished units could be delivered to JPL as listed below:

Unit No.	Date
1	10 Feb 1960
2	1 Mar 1960
3	1 Apr 1960
4	1 May 1960
5	1 Jun 1960
6	1 Jun 1960
7	1 Jul 1960
8	1 Jul 1960
9	1 Aug 1960

In addition to the nine VRU units listed above, ITTL was required to fabricate four sets of Laboratory Test Equipment. The first of these units was to be retained at ITTL for the duration of the contract to permit check-out of the completed VRU systems prior to shipment. The second through fourth LTE units were to be delivered to JPL for acceptance testing and subsequent system check-out.

C. Final Status

On December 18, 1959, the Vega project was officially cancelled. ITTL was directed to complete the documentation on all equipment designed as of that date and to proceed with fabrication on several sets of on-platform electronic assemblies and the ancillary electronic modules then in process. Any substantial purchase orders outstanding were to be cancelled and all excess parts and material then in inventory were to be prepared for shipment to JPL.

In accordance with instructions, ITTL reduced effort. The required on-platform and ancillary electronic assemblies were delivered to JPL on February 5, 1960.

On February 15, 1960, approximately two hundred vellum drawings, representing the then active drawings on file at ITTL, were transferred to JPL. During this period ITTL also returned to JPL all on-loan material including special tooling, jigs, fixtures, test equipment, gyros, accelerometers, and a Sergeant platform model.

The residual inventory, representing all material purchased by ITTL for use on the project, was packed in some four hundred cartons and shipped to JPL on April 21, 1960. The estimated value of this transferred material is of the order of $70,000.

The following section of this report describe specifically the VRU electronics, the Laboratory Test Equipment, and the mechanical engineering work performed.

Included herein by reference, but not attached as part of this report for reasons of practicality, are the thirty-two weekly technical meeting reports and all drawings prepared in the course of the project. Copies of these documents are currently in JPL's possession.

III. SYSTEM AND EQUIPMENT DESCRIPTION

A. Platform Electronics

The Vega platform design incorporates three types of electronic amplifiers mounted on the platform itself. The functions of these amplifiers are to process the inertial sensor signals and to control gyro temperatures. These amplifiers consist of gyro pre-amplifiers to raise the gyro signals above levels of noise that are encountered in transferring the information off the platform for further processing. Accelerometer amplifiers and demodulators are mounted on the platform for the same reason. The gyro heater amplifiers are also platform-mounted since the amplifier inputs and outputs are associated only with the gyros themselves.

It should be noted that the gyro heater amplifiers, or at least a substantial portion of these amplifiers, could be located remotely if on-platform space were not available. The penalty for remote location (in the ancillary package) would be six additional wires necessary in the flex lead cables of the platform.

Pertinent features of the three amplifier types are contained in the following discussion.

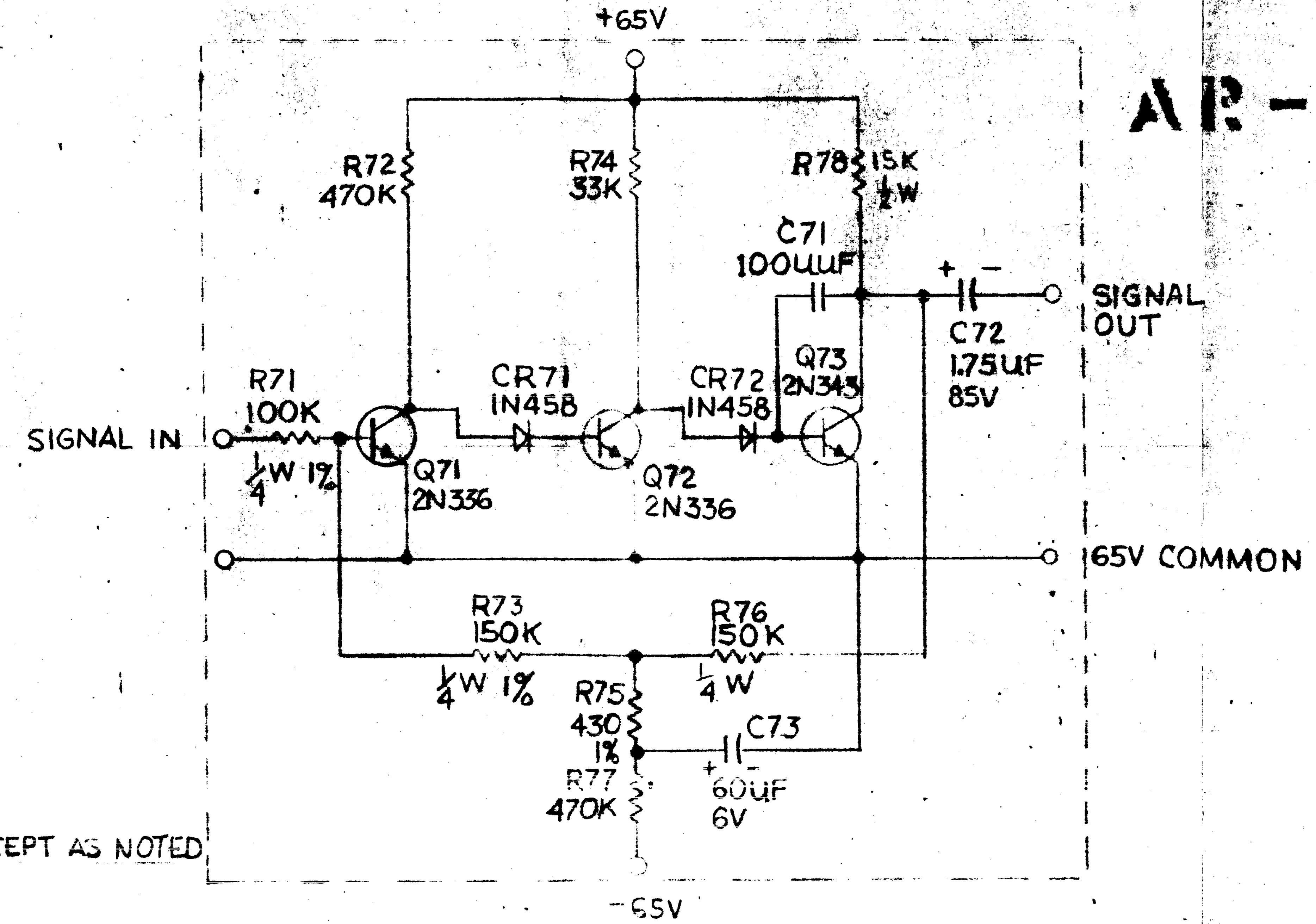
1. Gyro Pre-amplifier

The gyro pre-amplifier circuit is shown in Drawing 3162282. This amplifier was originally designed for 400 cycle operation, and, when the gyro signal frequency was raised to 4200 cycles, the only modification made was to change capacitor C71 from 500 to 100 $\mu\mu f$. This was a necessary step to provide adequate open loop gain at the higher operating frequency.

B 3162282

REV	CHANGE DESCRIPTION	P.L.	RELEASE DATE	DWN	CHK	STR	MATL PROC	ENGR	DES CHIEF

AR-4



NOTES:

3. ALL RESISTORS 5%, 1/4W EXCEPT AS NOTED
2. LAST NO'S
R78
Q73
C73
CR72
1. REF DESIGNATIONS
ALL ...
SY 3 SYSTEM III ...
SY 2 SYSTEM II ...
SY 1 SYSTEM 71 ... AR-4

DWG OR PART NO	DASH NO	DESCRIPTION	SPECIFICATION	STOCK SIZE REF DESIGNATION - ELEC DWG	MATERIAL	NO REQD	FIND NO

NEXT ASSY | USED ON VRU

RELEASE DATE OF DRAWING
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P.L.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY OVER ADDITIVE FINISH EXCEPT ORGANIC COATINGS.
TOLERANCES DECIMALS .XX ± .03 .XXX ± .010 ANGLES

PRE AMPLIFIER, GYRO STABILIZATION SCHEMATIC DIAGRAM
(VRU)

CROSS REFERENCE J3162280

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SCALE
CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY ITTL

DWG SIZE B | 3162282

SHEET 1 OF 1 | REVISION

It should be pointed out that both C72 and C73 could be reduced by a factor of 10 at the 4200 cycle frequency. This was not done on the Vega system as the design had proceeded past the point where these changes could have been accomplished without affecting schedule.

2. Gyro Heater Amplifier

The gyro heater amplifier schematic is shown in Drawing 3162281. In order to hold the gyro temperature to within $\pm 0.5^{\circ}$, it became necessary to eliminate the effect of supply voltage variations on the input differential amplifier. It was found that the common mode rejection of power supply fluctuations on this amplifier was not adequate to hold the temperature to the required tolerances so that a modification of this amplifier was required.

Increasing the common mode rejection was not a convenient fix on this unit so the solution chosen was a compensation system. The analysis of this modified circuit will be found in Appendix I.

3. Accelerometer Amplifier

The accelerometer amplifier used is a push-pull configuration for the entire amplifier. This configuration was used to minimize pickup signals.

High temperature operation of this amplifier induced spurious oscillation in the feedback loop around the first two stages in some units. This was eliminated by changing the feedback resistors R146 and R147 from 390K to 510K (Drawing 3162283).

In order to reduce the zero offset of the phase detector output, the detection diodes were matched in sets of four to within 10 mv. at two temperatures, $+20^{\circ}$ and $+82^{\circ}$ C. The matched sets were used on each bridge and positioned in the bridge configuration to minimize the residual unbalance.

B. Ancillary Electronics

The ancillary electronics package contains the balance of the electronics necessary for operation of the platform. This includes the platform stabilization system (demodulators, lead amplifiers, modulators and power amplifiers), LEO amplifiers, power and signal switching circuits, and special monitoring circuits.

Although no complete system was assembled and tested at the time of cancellation, a description of the parts comprising the ancillary box will be made to describe the mode of operation.

1. Lead Compensation Amplifier

The lead compensation amplifier shown in Drawing 3162605 receives the output of the gyro pre-amplifiers located on the platform. The signal is demodulated in a phase detector and filter system and then processed by two sequential operational type amplifiers. The RC networks associated with the two operational amplifiers provide for dynamic damping and operational response requirements of the stable platform system. The second operational amplifier also contains a non-linear DC feedback network to compensate for the effect of controlling power to both phases of each gimbal torquer.

Some preliminary investigation of the operational amplifiers has indicated that the differential input stage transistors should be 2N338 instead of the current 2N336 type. This change will reduce the DC offset to meet the 150 mv output offset which has been specified for this amplifier.

2. Modulator

The output of the lead compensation amplifier drives a dual modulator system shown in Drawing 3162606. The outputs of the two modulators are quadrature phase 400 cps signals which provide two phase power to a gimbal torquer. One modulator provides for phase reversal of its output, related to the polarity of the input, while the other modulator provides only amplitude variation for the input signal. Thus the two modulator outputs constitute the signals necessary to drive a two phase torquer.

3. Gimbal Torquer Amplifier

The output of each modulator drives a gimbal torquer amplifier (Drawing 3162607).

This amplifier provides a power system to furnish 400 cycle power to the gimbal torquer winding. Two such amplifiers are used for each gimbal torquer. Thus, when no drive is required on the torquer, the reference phase power is removed, minimizing platform heating. The square law torquer characteristics of this type of drive system are compensated for by the non-linear amplification achieved by the lead compensation amplifier discussed previously.

It should be noted that six gimbal torquer amplifiers are used in the system, two for each axis, and three each are required for the lead compensation and modulator circuits.

4. LEO Amplifiers

The leveling, erection, and orientation (LEO) amplifiers used in the system are shown in Drawing 3162615. These amplifiers are essentially power amplifiers to provide pattern signals to the gyros for platform orientation. The inputs are derived from operational amplifiers not a part of the platform system, except that the inputs are derived from the accelerometer signals. The operational amplifiers provide for the coarse and fine cage mode signals, and the LEO amplifier described here, provides power amplification of these signals. This LEO amplifier is chopper stabilized so that it may be possible to use it alone for both coarse and fine cage by incorporating the switching of the integrating capacitor and the corresponding input signals from the accelerometers into this system.

5. Platform Control System

The stepping switches to turn on and orient the platform system are located in the ancillary package. The two stepping switches required for this operation include one for power and one for signal switching. A schematic of the basic switching system is shown in Drawing 3162662.

6. Other Equipment in Ancillary Package

Additional equipment required in the ancillary package is included in the following list:

a. Inductosyn signal amplifier — Drawing 3162656

b. Gyro heat monitor circuit (Transformer Assembly — T262) — Drawing 3162287

c. Accelerometer amplifier filter capacitors.

C. Mechanical

At the time of termination of the contract, the mechanical portions had reached the following degrees of completion: mechanical engineering — 65%, design and drafting — 85%, shop fabrication — 23%, assembly — 20%, test — 5%, tooling program — 80%, planning and scheduling — 95%, and purchasing — 90%.

This project was launched with the supply, by JPL, of Sergeant drawings and prototype model.

Among the major milestones of accomplishment in this program are the items enumerated and discussed below.

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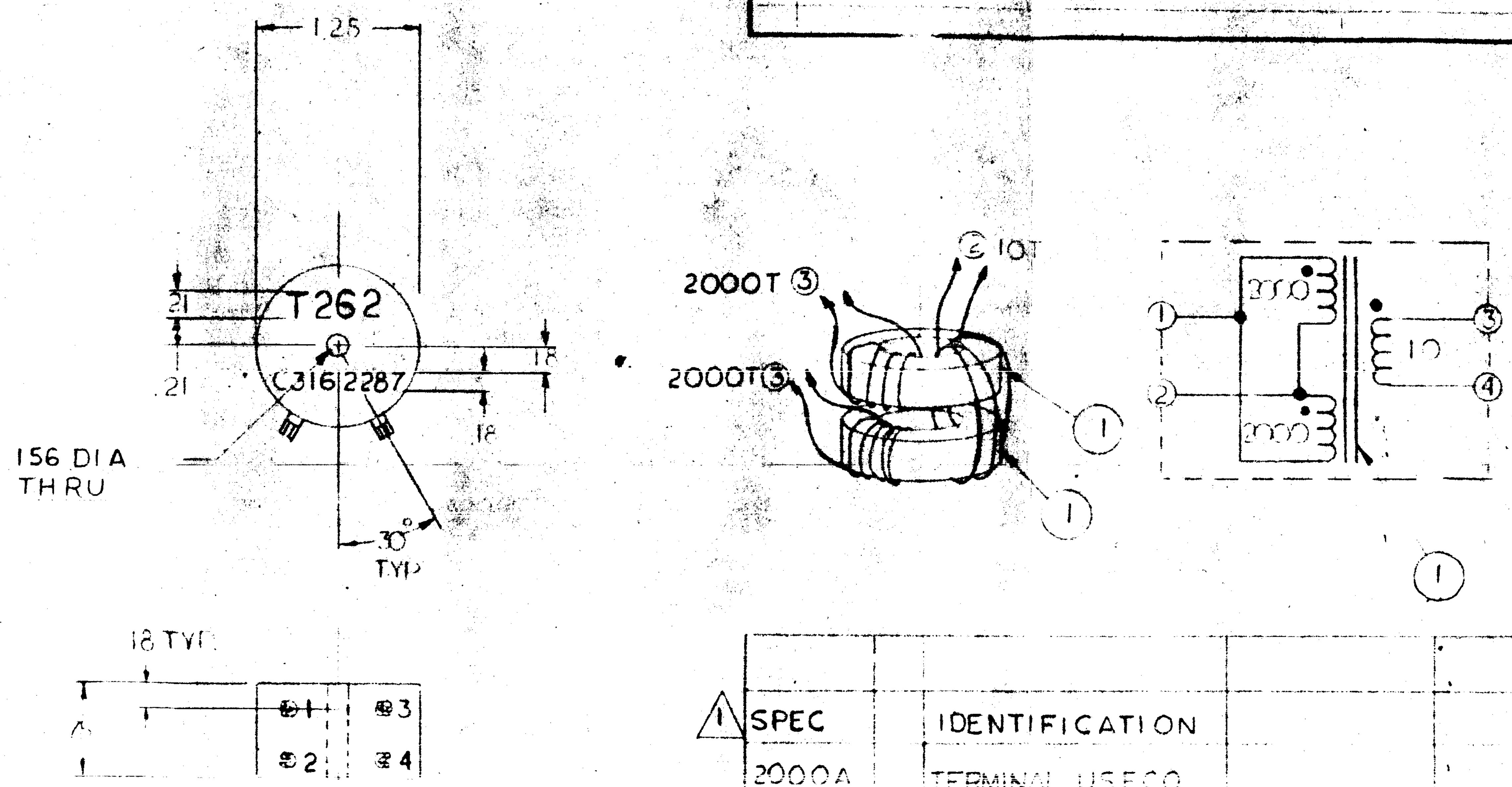

DWG OR PART NO	DASH NO	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO REQD	FIND NO
SPEC		IDENTIFICATION					5
2000A		TERMINAL, USECO					4
#37		WIRE, HEAVY FORMVAR					3
#20		WIRE HEAVY FORMVAR					2
51000-2A		CORE, MAGNETICS INC.					1

NEXT ASSY	USED ON
	VIRU

RELEASE DATE OF DRAWING

DWN HOFT
CHK
STR
MATL PROC
CHIEF DFTM
ENGR
DES CHIEF
PL

TRANSFORMER
ASSEMBLY T262
(ANCILLARY ELEC)

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY OVER ADDITIVE FINISH EXCEPT ORGANIC COATINGS

TOLERANCES DECIMALS XX ± .03 .XXX ± .010 ANGLES ±

CROSS REFERENCE

SCALE

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CLASSIFICATION

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1. JPL furnished detail drawings of inner element casting, inner gimbal, and outer frame castings.

ITTL began active design participation with construction of a wooden model of the inner element casting. This model included additions to the casting for mounting the various platform electronic units. This first model also included a design change in that two gyros were moved to allow better use of the space for electronics.

After this wooden model was delivered, we made wood blocks simulating tentative electronic packages, and constructed a fixture for supporting the inner element to demonstrate mechanical clearance of the assembled unit. Changes were made to the detailed JPL furnished drawing, and JPL proceeded with pattern making and foundry work to obtain these castings.

JPL delivered castings of the Sergeant gimbals applicable to VRU, and ITTL proceeded with fabrication of these gimbals for the prototype models.

ITTL fabricated the first inner element casting for use as a fixture in which to test the platform electronics for type approval acceptance at JPL test facility.

2. Designed sheet metal chassis for mounting platform electronic assemblies. This design represented a departure from normal design of JPL missile electronic units as represented by Sergeant equipment. Sample models of these chassis were constructed and assembled into a prototype equipment. This equipment was tested by JPL, and no failures were experienced in the type approval vibration tests.

3. Fabricated prototype spindles, bearing housings, flex lead shields, and other small parts for JPL to use in their lab model.

4. Designed and detailed the electronic units to be mounted in the inner element. Complete drawings were made of the various circuit board lay-outs and their assemblies into the sheet metal chassis. Basically, this design uses epoxy-glass component boards cemented into place on the chassis.

5. Conducted experiments in the area of bonding the electronic components in place. Many different types of bonding materials were tried and final results indicated success could be expected in holding the electronics with a very minimum of bonding material. Sample process specifications are attached as Appendix III.

6. Conducted extensive investigation into the problem of design in the spindle axis areas and the application of flex-leads at the various axes. Most of the major problems in these areas stemmed from potentiometers, resolvers, spindles, bearings, and other items presenting space restrictions that made proper flex-lead design critical and difficult. Several models were constructed to demonstrate the feasibility of tentative flex-lead designs.

7. The selection and application of the gimbal ball bearings involved lengthy analysis of the fundamentals of ball bearings and mechanical structures to support them. High contact-angle bearings were chosen which resulted in more stringent requirements of mechanical tolerances and closer analysis of thermal expansion problems in the equipment. ITTL conducted a theoretical investigation into the geometry of ball bearings. This produced a report, a copy of which is attached as Appendix IV.

8. Designed and fabricated a model of the wiring of the inner element.

9. Made assembly layouts. These layouts located torquers, established clearances, and provided information from which stops for gimbal travel could be located. These design layouts also provided information showing the necessity of rather extensive changes in dimensioning and tolerancing of the gimbal casting drawings.

10. Designed the outer cover and added designs to the lower base to include the application of RF shielding, cable connectors, inductosyns mounting, blower mounting, a new blower duct assembly, cover mounting clamp, and mechanical mounting of the VRU in the missile. The clamp selected is the Marman type. This type clamp provides even contact pressure with consequent improvement in RF shielding. As a result of tests conducted at JPL, the blower housing was found to be inadequate and the necessity of a recirculating duct was indicated. ITTL designed and built a model of such a duct which resulted in improvement of the distribution of air within the unit.

D. Laboratory Test Equipment

The Laboratory Test Equipment sets were designed to supply all of the input power which the VRU normally derives from the vehicle and to provide a convenient and accurate means for operating VRU equipments and checking performance. To satisfy this end, each LTE unit was comprised of the following equipments.

Power Sources –

+ 150 volts
– 150 volts
+ 65 volts
– 65 volts
+ 18 volts
– 18 volts
400 cps, 2ϕ, 110 v
400 cps, 3ϕ, 28 v
4200 cps supply
8400 cps supply
380 cps supply

Control and Metering Panels –

Ground Control Unit
Gimbal Angle Monitoring Unit
Gyro Signal Panel
Gyro Torquer Panel
Gimbal Torquer Panel

Design of each LTE unit provided for mounting the listed equipments in a single relay rack cabinet. To insure thermal isolation for the more sensitive measuring equipments, the rack cabinet was designed as two separate compartments so that the high wattage power supplies would have their heat load removed independently of the cooling for the metering panels.

As of the effective project cut-back date, the percentage completion of the four LTE units was as shown.

	LTE Unit No.			
	1	2	3	4
Design	90%	90%	90%	90%
Parts Purchased	75%	75%	75%	65%
Construction	50%	50%	40%	30%

APPENDIX I

GYRO HEATER AMPLIFIER COMPENSATION

The gyro heater amplifier circuit that was designed for use on the Sergeant was found to be inadequate to hold the gyro heater temperature to within $\pm$ 0.5^{o} with supply voltage fluctuations. Based on static operation characteristics of this heat control system, the common mode rejection of the input amplifier was found incapable of reducing the effect of supply voltage variations on the operating point of the amplifier. The following analysis points up the reason for this problem and describes the design change that was made to reduce this effect.

Figure I(a) shows the original input stages of the gyro heater amplifier. For the static analysis it shall be assumed that the gyro operating temperature will be equal to the temperature at which the bridge input circuit is balanced, with nominal supply voltage (28 volts).

For balance conditions, the base potential of the input differential amplifier is:

Equation (1) $$E_B = \frac{E_s}{2} + \frac{I_b R_a}{2}$$

The emitter potential will be:

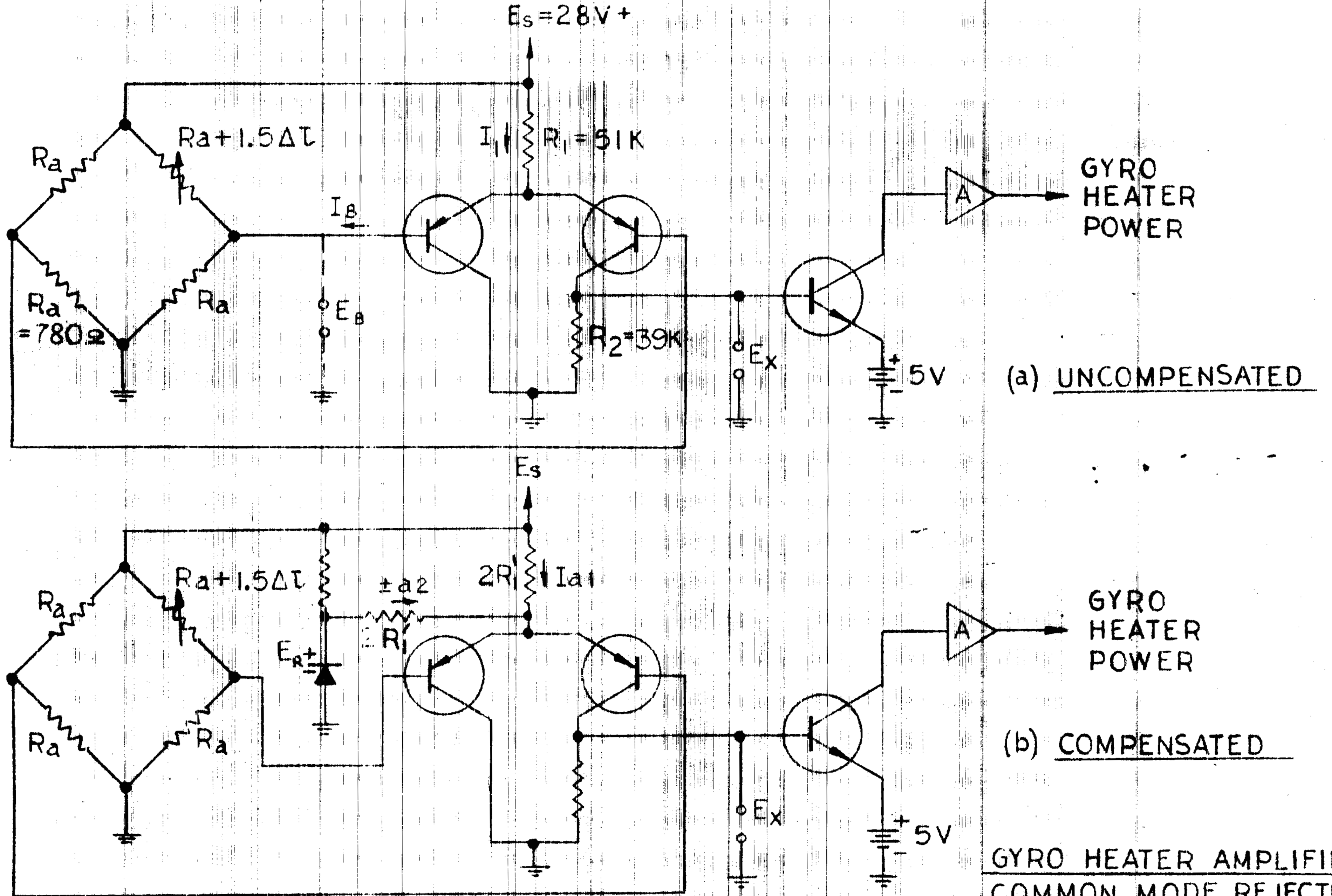
(2) $$E_E = E_B + E_{eb} = \frac{E_s}{2} + \frac{I_B R_a}{2} + E_{eb}$$

The sum of the emitter currents will be

(3) $$I_1 = \frac{E_s - E_E}{R_1},$$

which upon substitution becomes,

(4) $$I_1 = \frac{E_s}{2R_1} - \frac{I_B R_a}{2R_1} - \frac{E_{eb}}{R_1}$$



(a) UNCOMPENSATED

(b) COMPENSATED

GYRO HEATER AMPLIFIER COMMON MODE REJECTION

FIG. I a,b

Under balanced conditions, the output voltage of the differential amplifier can be described as

$$(5) \qquad E_x = \frac{I_1}{2} R_2 = \frac{R_2}{4R_1} \left[E_s - I_B R_a - 2E_{eb} \right] ,$$

if the succeeding stage is not conducting. The transition region of conduction for the next stage defines the point at which heat will be applied to the gyro, so that a balance condition requires that $E_x \approx 5.7$ volts.

If we assume that the emitter-base potential (E_{eb}) and base current (I_B) are small terms and are relatively unaffected by supply voltage, equation (5) can be written as:

$$(5)' \qquad E_x \approx \frac{R_2}{4R_1} E_s$$

and,

$$(6) \qquad \frac{\partial E_x}{\partial E_s} = \frac{R_2}{4R_1}$$

Evaluating equations (5)′ and (6) for a balanced condition,

$$(7) \qquad E_x = \frac{39k}{4(51k)} \; 28 \text{ v} = 5.35 \text{ volts.}$$

Equation (7) shows that for a balanced input condition, the amplifier is near the conduction point of the second stage and, therefore, quite satisfactory. However, equation (6) indicates that E_x is a function of E_s,

$$(8) \qquad \frac{\partial E_x}{\partial E_s} = \frac{39k}{4(51k)} = 0.19$$

In order to overcome this offset due to supply voltage fluctuations, the bridge will unbalance by the change in E_x, reduced by the gain of the differential amplifier. Thus, an input signal from the bridge (E_{in}) will be:

$$(9) \qquad \Delta E_{in} = \frac{0.19}{A} \Delta E_s$$

For A = 50 (differential amplifier gain),

$$(10) \qquad \frac{\Delta E_{in}}{\Delta E_s} = \frac{0.19}{50} = .0038$$

Equation (10) indicates that for each volt change in supply voltage, the differential bridge input must change by 3.8 millivolts to maintain the amplifier in its active region.

The input voltage signal to the amplifier is approximately 9 millivolts per ohm change in the sensing resistor. The sensing resistor would, therefore, require a change:

$$(11) \qquad \Delta R = \frac{3.8}{9} \Delta E_s = .42 \Delta E_s,$$

or 0.42 ohms change per volt variation in supply. This agrees well with the 0 33 ohms change per volt of power supply variation that was measured on the circuit.

Figure I(b) shows the circuit modification that was made on the Vega system to compensate for this gyro heater drift. The emitter current source was modified so that under balanced conditions

$$(12) \qquad I_{a1} = \frac{E_s - E_e}{2R_1}$$

$$(13) \qquad I_{a2} = \frac{E_R - E_e}{2R_1}$$

$$(14) \qquad I_1 = I_{a1} + I_{a2} = \frac{E_s}{2R_1} + \frac{E_R}{2R_1} - \frac{E_e}{R_1}$$

which reduces, from equation (2), to

$$(15) \qquad I_1 = \frac{E_R}{2R_1} + \frac{I_B R_a}{2} + E_{eb}$$

This removes the dependence of the sum of emitter currents from direct variations of supply voltage (E_s) and relates it only to variations of the zener reference potential (E_R) and transistor operating potential variations.

APPENDIX II

EPOXY RESISTIVITY TEST

PROBLEM:

To determine the resistivity of glass melamine component boards treated with the Jones-Dabney epoxy coating described in Section F, Appendix III.

1) For exposure to normal ambient temperature and humidity

2) After soaking in water for a 24 hour period.

PROCEDURE:

The resistance of the specimen was directly measured with a Freed Transformer Megohmmeter. The specimen was a 1/16" thick fiberglass board (identical to the material used for the electronic assemblies) coated on one side with the epoxy coating that averaged .011" thick. The sample was sandwiched between aluminum foil with care given to insure contact with the electrodes over the entire area (30.25 $in.^2$) of the sample.

As the experiment control, a number of resistance readings were made to determine the resistivity of the uncoated fiberglass board. The second test consisted of measuring the resistance of the epoxy-coated board and computing the resistivity of the epoxy. For the third test, the coated specimen was immersed in a vat of water for 24 hours and then its resistance was measured.

RESULTS:

Resistance of the glass melamine board alone (R_B) was measured to be $1 \times 10^5 \pm .2 \times 10^5$ megohms. The resistivity of the board (ρ_B) is then given by

$$\rho_B = \frac{R_B \ (A)}{\ell_B} = \frac{1 \times 10^{11} \times (5.5)^2 \times 2.54}{.068} = 1.1 \times 10^{14} \text{ ohm-cm}$$

The resistance of epoxy covered board (R_T) measured 20×10^5 megohms. The resistivity of the epoxy coating (ρ_e) is then given by

$$\rho_e = \frac{(R_T - R_B)\ A}{\ell_e} = \frac{19 \times 10^{11} \times 5.5^2 \times 2.54}{.011} = 1.3 \times 10^{16} \text{ ohm-cm}$$

The resistance of the coated board after 24 hour immersion in distilled water measured 1×10^5 meg-ohms, from which the resistivity, ρ_W, is calculated to be $\dfrac{1 \times 10^{11} \times 5.5^2 \times 2.54}{.077} = 9.9 \times 10^{13}$ ohm-cm. This value corresponds well with the characteristics of the dry component board and indicates that no leakage resistance difficulties should arise from the use of this epoxy on the electronic component mounting boards.

APPENDIX III

A. PROCESS FOR CEMENTING WITH THERMOSETTING RESIN (EPON)

1. Purpose

The purpose of this Standard Process Specification is to set forth methods by which several organic and inorganic materials may be cemented with one type of thermosetting resin adhesive.

2. Apparatus and Materials

a. Epon Adhesive 6, obtained from:	Shell Chemical Corporation 1008 W. 64th Street Los Angeles 17, California
b. Ethylene Diamine	
c. Epon Curing Agent A, obtained from:	Same as above

3. General

a. Quantity: Care should be taken to mix only enough adhesive and curing agent for four hours use at room temperature since this is the extent of the mixture's useful life. For best results, it is recommended that the mixed material be kept in a covered vessel.

b. Polyethylene and fluorinated thermoplastic polymers cannot be successfully bonded with Epon 6.

c. More consistent results will be achieved in curing by the use of Ethylene Diamine. Curing Agent A as supplied by Shell Chemical Corporation may be used as an alternate.

4. Procedure

a. Preparation of Surfaces

1) Metals: All surfaces to be bonded must be clean and free from grease. Freshly machined and sanded surfaces are satisfactory, provided no oil or grease is present. Only aromatic type solvents may be used to remove such contaminations.

Special Chemical surface preparations such as etching, pickling, etc. may give better bond strengths than those obtained with mechanically prepared surfaces. The following treatment is suggested for aluminum.

a) Degrease with solvent and dry.

b) Clean the surface with a chromic acid solution by immersion at 150° – 170° F. for five to ten minutes. The solution is prepared as follows:

By weight:	10 parts	Sodium Dichromate
	50 parts	96% Sulfuric Acid
	340 parts	Distilled water

Dissolve the dichromate in most of the water, add sulfuric acid while stirring carefully, then, add the remaining water.

c) Rinse the metal thoroughly with water and air dry, or dry with air blast.

d) The following treatment is for etching copper and copper alloys prior to application of cement:

Immerse for one to two minutes at room temperature in the following solution:

following solution:	42% Ferric Chloride Solution	15 cc.
	Concentrated Nitric Acid	30 cc.
	Distilled Water	200 cc.

Thoroughly rinse in water, air dry, or dry with air blast.

2) Plastics: All surfaces to be bonded must be free from oil, grease, etc. Any release agent remaining on the surface at the plastic should be removed by solvent, sanding, or buffing.

3) Wood: A freshly sanded surface on wood is required for maximum bond strength.

4) Rubber: Surface etching of rubber is desirable to provide maximum bond strength. A satisfactory bonding surface may be obtained by using one of the following ovolizing techniques.

e) Immerse the rubber in concentrated sulfuric acid (specific gravity 1.84) for five to ten minutes for natural rubber or ten to fifteen minutes for synthetic rubber. After washing thoroughly with water and drying, the brittle surface of the rubber should be broken by flexing so that a finely cracked surface is produced.

f) Coat the surface to be bonded with a paste of Barium Sulfate and sulfuric acid in a consistency which will not run, and allow to stand for 30 minutes to 2 hours depending on type and hardness of the rubber. After washing thoroughly with water and drying, the brittle surface of the rubber should be broken by flexing so that a finely cracked surface is produced.

g) It may be necessary to wash with diluted caustic solution to insure neutralization of residual acid which, if not removed, will consume some of the curing agent, thereby, weakening the bond strength. The surface is then ready for the application of the adhesive.

b. Preparation of Adhesive: The following mixture should be made as accurately as possible: One hundred parts by weight of Epon Adhesive six to approximately six parts by weight of Ethylene Diamine or Epon Curing Agent A. This is satisfied by 6.8 grams of Epon six to 0.4 gram of either Ethylene Diamine or Epon Curing Agent A.

5) In order to insure correct ratios, it is suggested that exact weighing be resorted to and that 30 ml glass beakers be employed as mixing receptacles with glass stirring rods.

c. Application of Adhesive

6) Application: Spread a thin layer of adhesive evenly on each of the surfaces to be bonded and press together gently. Only contact pressure is required. The adhesive may be conveniently applied with wooden applicators similar to the metal tools customarily used to spread linoleum mastic. Final spreading can be done with either a wooden paddle or a hand roller.

7) Time: Parts should be assembled immediately after spreading the adhesive as there are no volatile solvents present. Excessive exposure of the spread adhesive may result in partial evaporation of the curing agent and subsequently produce a weak bond.

8) Quantity: The quantity of adhesive required should be determined by trial as it depends to a considerable extent upon the complexity of the part being bonded. Glue line thicknesses of 0.0005 to 0.04 inch produce no significant variations in bond strength. In bonding soft or absorptive woods, a sufficient thickness of adhesive should be used to avoid excessive absorption of the uncured adhesive and reduction of the glue line. The use of an unimpregnated cloth or glass fiber carrier in the glue line can considerably improve the strength by uniformly distributing the adhesive over the area to be bonded.

d. Curing: Curing may be accomplished at either of the following:

Temp. ^{o}F.	Time
165	2 hours
200	45 minutes

At room temperature, about 20% of the ultimate strength is developed in eight hours. In most cases, this permits removal of clamps used to hold an assembly in position. Handling strength is developed in about two days, and the maximum cure is obtainable at room temperature in about six days. Curing at room temperature results in some embrittlement and relatively poor, low temperature characteristics. If heat is used in curing, it is recommended that temperatures in excess of 240° F. not be used, as the time becomes critical and an appreciable reduction in the properties of the bond may result.

NOTE: Ovens should be calibrated to insure correct temperatures.

e. Properties: Bond strengths as required may be obtained by adherence to temperatures and time noted in the preceding subsection d.

5. Control Measures

No control measures required, except strict adherence to outlined procedure.

B. PROCESS FOR CEMENTING WITH THERMOSETTING RESIN

1. Purpose

The purpose of this Standard Process Specification is to establish the procedure and material to be used in obtaining a satisfactory bond between two surfaces with one type of thermosetting resin.

2. Apparatus and Material

Bondmaster M-642

Hardener - CH44, plus 0.5% (by weight), Fluorescein U.S.P. Dye.

Both of the above to be supplied by: Rubber and Asbestos Corp.
Bloomfield, New Jersey

Bondmaster M-642 and CH44 shall be mixed by operator, prior to use, in a weight ratio of 15 to 1.

NOTE 1: The useful life of the adhesive after mixing is two to four hours.

NOTE 2: As alternates, the following materials may be used for the same purpose and in the same way as indicated above.

a. Houghton Laboratory Hysol 2050 Resin with Hardener "A."

b. Furane Plastics, Inc., Epibond 102 with Hardener HN 951.

3. General

a. Fit: Parts should be closely fitted and the area to be bonded, masked, so that excess adhesive will not be applied to unwanted areas.

b. Cleaning: Areas to be bonded should be thoroughly cleaned and dried before applying adhesive.

4. Procedure

a. Application of Adhesive: Adhesive may be applied with a metal spreader, brushed, dipped, or roller coated. Prior to joining adhesive coated surfaces, the solvent should be allowed to evaporate 15 to 30 minutes. Coated surfaces should be clamped together so that there is no relative movement during hardening.

Excess adhesive should be cleaned from around the joints before the resin sets, by the careful use of acetone or Toluol.

Adhesive containers and spreading equipment may be cleaned with acetone.

b. Drying Time: In order to avoid runs, sags, and/or undue capillarity, a set time of 30 to 90 minutes should be allowed between final application of the adhesive and the time of placing the part in the curing oven.

c. Cure: Cure may be obtained at the following temperatures and time durations:

150° F. to 160° F.	for 2 hours	minimum
160° F. to 170° F.	for 1–1/2 hours	minimum
180° F. to 190° F.	for 1 hour	minimum.

If the part is large, with considerable thermal inertia, the curing time may have to be increased by approximately 15 minutes.

5. Control Measures

The fluorescent dye (Par. 2) incorporated in the hardener permits visual inspection under black light for purposes of detecting adhesive contamination as on bearing races, potentiometer surfaces, etc. It also permits the detection of the presence of sufficient adhesive in required areas.

C. PROCESS FOR CEMENTING ELECTRONIC BOARDS (EPOXY GLASS FIBRE) TO ANODIZED ALUMINUM FRAMES

1. Purpose

The purpose of this Standard Process Specification is to set forth methods whereby consistent results may be obtained in cementing glass fibre boards to anodized aluminum frames.

2. Materials

a. A-2 cement — Kits as made by Armstrong Products Company
Argonne Road
Warsaw, Indiana

b. Activator A

3. General

a. Care should be taken to only mix enough ingredients to be used up in fifteen minutes after which time the mixture gels and cannot be used.

b. Mixing ratio: 12 grams of A-2
17 drops of activator A

c. Cure: Three hours at 140° F.

4. Application

Clean parts to be assembled by dipping or wiping with Benzine, allow time for Benzine to evaporate, and apply adhesive to both parts to be assembled with a brush or spatula. Press parts together to squeeze excess material from joint, but do not squeeze so hard as to remove all of it. Excess material may be removed by wiping with Benzine or with Methyl Ethyl Ketone.

NOTE: These materials are toxic, avoid inhaling the vapors. Protect the hands with DuPont Pro-Tek hand cream. After using, wash the hands with alcohol and then several times with soap and water.

D. MIXTURE FOR ENCAPSULATION OF ELECTRONIC COMPONENTS

1. Parts by Weight: (Source: Jones Dabney)

   a. 100 grams Epi–Rez No. 510

   b. 100–150 grams quartz flour

   c. 20 grams Epi Cure No. 82

2. General

Pot life is approximately 23 minutes at room temperature. Cure time is four to eight hours at room temperature. Do not exceed 140° F. oven temperature if cured in an oven. Warning, internal temperature is about 212° F. for 1/8" sections and as high as 250° F. for 1/2" sections—heavier sections have a correspondingly higher temperature rise which could damage transistors.

E. REPORT ON A THERMAL CONDUCTING THERMO SETTING ENCAPSULATION COMPOUND

1. Mix found to be Most Satisfactory

	Parts by Weight		Supplier
Resin	400 grams	– atomized anodized aluminum powder	Metals Disintegrating Company, Inc. Emeryville, California
	70 grams	– Epi–Rez No. 507	Jones Dabney
	30 grams	– Epi–Rez No. 510	
	500 grams		
Hardener	47.25 grams	– hexahydropthalic anhydride	National Aniline
	5.25 grams	– tetrahydropthalic anhydride	National Aniline
Accelerator	3 grams	– Syntex 3154	Jones Dabney

2. Procedure

a. Mix the resins and aluminum powder together. It will be required to heat to 150° F. to intimately mix the resin and aluminum powder. Degas at 30 cm of mercury to remove entrained air.

b. Mix the anhydrides in a separate container. It will be required to heat to 180° F. to mix these since they are solids below this temperature.

c. Mix resin mixture and anhydride mixtures together while both mixtures are at 180° F. Stir the two mixtures intimately, add the Syntex and degas at 10 cm mercury. Cool to room temperature and use for encapsulation or place in a refrigerator for later use.

d. Pot life of blend is approximately two weeks in the refrigerator.

e. Cure time is approximately six to eight hours at 212° F.

F. PROCESS SPECIFICATION FOR A FLEXIBLE ENCAPSULATION COMPOUND (THERMOSETTING) FOR ELECTRONIC COMPONENTS

1. Purpose

The purpose of this specification is to provide a method of attaining consistent properties when encapsulating electronic components.

2. Materials and Proportions

a. 55 grams – Epi-Rez 507 – Jones Dabney Company

b. 45 grams – Epi-Rez 510 – Jones Dabney Company

c. 47.25 grams – Hexahydropthalic anhydride – National Aniline

d. 5.25 grams – Tetrahydropthalic anhydride – National Aniline

e. 3. grams – Syntex No. 3154 – Jones Dabney Company

f. 3. grams – Catalyst "D" – Shell Chemical Company

3. Mixing

Blend Epi-Rez 507 and Epi-Rez 510. Mix hexahydropthalic and tetrahydropthalic anhydrides and heat gently to 180° F. to melt the anhydrides. Add the anhydrides to the 507 and 510 and blend in, add the Syntex 3154; pot life of this mix is about two weeks at room temperature. At time of use, add the three grams of Catalyst "D" and blend in. This mix, after addition of Catalyst "D", has a pot life of about eight hours.

Be sure component boards are free of oils by washing in benzine, then, bake for ten minutes to remove all benzine.

Apply mix to boards with either a brush or by dipping.

Cure at 175° F. for four hours.

Properties of cured resin should have the following properties: (approximated)

<u>Physical Properties</u>

Tensile strength	2500 psi
% elongation	65 %
hardness (Shore A)	92
water absorption	2 %
% loss in weight after aging 24 hours at 300° F.	1.5%

<u>Electrical Properties</u>

Dielectric strength/mil	380 volts
Dielectric constant/frequency 1 MC	3.7
Power factor/frequency 1 MC	.028
Volume resistivity—CM.	5×10^{12} ohms
Surface resistivity—CM.	10×10^{12} ohms

APPENDIX IV

ASSEMBLY AND ADJUSTMENT OF THE GIMBAL BEARINGS

The ball bearings selected for this application are the Barden Corp. Bearing Number SR10SS6. Table 1 and Figure 1 represent the operating characteristics of these bearings.

	First Gimbal	Second Gimbal	Third Gimbal
Max. Thrust – lbs.	70	90	110
Minimum Preload – lbs.	15	20	25
Torque per pair gm–cm			
Starting	50	72	96
Running	25	36	48
at max. thrust	100	120	160
Contact angle			
Initial	18.6° min;	24.7° mean;	31.8° max.
Mounted	21° min;	28.3° mean;	34° max.

Table 1 — Bearing Characteristics of SR10SS6

The minimum preload requirements are as shown in Table 1. The bearing torque should remain less than 150 gm–cm throughout the operating range. Taking the acceleration, shock, and vibration environments into account, this means that a test bench setup cannot allow a bearing torque of greater than 50 gm–cms. This is true because a test bench setup only experiences axial accelerations due to the basic supported platform weight.

In consequence, the proper procedures for the assembly of the gimbal bearings must be capable of meeting these two conditions.

The proper preloading of a gimbal ball bearing in a system, as complicated as an inertial platform, is a very tedious operation. The permissible latitude in the SR10SS6 bearing axial preload deflection is of the order of ten millionths of an inch. That is to say that a change of ten micro-inches in the axial deflection will change the bearing preload from 15 pounds to 13-1/2 pounds. This will decrease the potential acceleration support from 70 to 64 pounds, and also decrease the bearing torque 7 gm-cms. Roughly, this is a ten per cent change of operating conditions.

To account for all the mechanical factors that can have overall effects that are significant when compared to only ten micro-inches is a difficult problem. In all reasonability it is impossible to account mathematically for all factors down to this degree and, hence, any assembly procedure intended to set up the SR10SS6 bearing in the VRU platform will require a design to decrease all system random variables to below this ten micro-inch, ten per cent threshold.

A reasonable assembly procedure that has proved effective in the past is that procedure used on the Sergeant platform and which is described in the JPL engineering report 24-21 of 6/10/59. The technique was to calculate a preload shim thickness (S), see Figure 2, by adding the two physical dimensions, the axial step, C, and the race, to housing distance, D. These dimensions were physically measured during assembly and appropriate corrective terms were added to account for the difference between the bench set up conditons and the platform operating conditions. These corrective terms were:

F = Bearing deflection for desired preload.

G = Deflection due to weight of gimbal on lower bearing while measuring C and D.

H = Dimensional change due to differential thermal expansion between gimbals caused by thermal gradients across gimbals.

J = Differential expansion of adjacent gimbals due to platform ambient temperature changes.

K = Correction for deflection due to previously preloaded axis being unloaded by loading of next axis.

L = Allowance for preloading deflection of the outer race and inner race gimbals.

M = Correction for change of internal axis preloads as platform changes from bench conditons to operating conditions.

S = Shim size.

$$S = \bar{E} + 2\bar{F} - \bar{G} - \bar{H} + J + K + L + M \quad (1)$$

The use of equation (1) provides a satisfactory answer to the assembly problem if the value of the shim thickness (S) can be determined to the required accuracy. Study of equation (1) indicates that the shim size has to accept a tolerance buildup contributed by nine separate factors.

$$\Delta S = 1 + \frac{Kb}{KG_i + KG_o} \Delta F \tag{2}$$

ΔS = $\pm$ tolerance on shim size inches

K_b = Spring stiffness of bearing lbs./inch

KG_i = Spring stiffness of inner race gimbal lbs./inch

KG_o = Spring stiffness of outer race gimbal lbs./inch

ΔF = Change of bearing axial preload deflection inches

Equation (2) indicates the susceptability of the bearing axial preload deflection to changes in shim size. Since the average spring constant of the gimbals is about 3×10^5 lbs./inch and the bearing stiffness at normal preloads is about 0.8×10^5 lbs./inch. Equation (1) becomes,

$$\Delta S = 1.133 \Delta F \tag{3}$$

and if the ten per cent point of ΔF = ten micro-inches is considered, then the shim size can only vary $\pm$ 11 micro-inches —— a small value indeed. This impresses a stringent requirement for accuracy in grinding shims. Selection of the right ones can probably best be accomplished by a trial-and-error process using shims made to the best practicable tolerances.

Equation (1) is still valuable as a first approximation. If the results derived from equation (1) can lead to an initial bearing assembly, that at operating conditions, will produce a positive preloading of the gimbal bearings, it will be possible, through bearing torque tests, to quite accurately determine what shim size will yield the correct preload. Hence, ignoring assembly difficulties, only one trial-and-error attempt would be necessary. In order that equation (1) be capable of providing this type of a first approximation, it will be necessary to determine S to within about $\pm$ 250 micro-inches. If this is to be done by an addition of nine separate measurements, each measurement should ideally have an individual accuracy of 28 micro-inches (50 micro-inches would probably work reasonably well). This tolerance is within reason and can be produced with good shop and inspection practices.

In conclusion, the recommended procedure for assembly of the VRU platform, with the SR10SS6 gimbal bearing, is to calculate a shim size based upon assembly measurements, bearing and gimbal experimental data, and equation (1). Upon assembly of each gimbal, it will be necessary to induce the operating conditions of temperature and preload so that bearing torque measurements can be taken to indicate the corrections necessary for proper assembly. In this manner a platform can be built up so that once fully assembled, after one trial-and-error selection of proper shims, there will be no need for further disassembly because of improper bearing preloads.

It is to be noted that the assembly must be brought to operating temperatures before torque tests are made. This will always be necessary because bench assembly of the platform will always result in a loose bearing assembly (play of .001 to .002 inches). The design of the test and assembly equipment to do this job was not completed at the time of termination of the project.

Apart from the problems of bearing assembly is the effect of bearing misalignments on preload and consequently of platform performance. Analysis shows that there is no experimental way of determining what the misalignment of the bearings is after assembly. These effects can be significant and appear as a degradation of the effective acceleration, vibration, and shock capability of the platform.

Selection of a nominal bearing preload is accomplished by inducing just enough axial bearing deflection so that when one bearing carries the entire acceleration load the other bearing is only lightly loaded. It is this light residual load that prevents any of the bearing balls from coming unseated and ruining the bearing by brinneling.

When bearing misalignments are introduced by concentricity and parallelism tolerances of the bearing mountings, the end result is an uneven loading of the balls in the bearing. Under axial accelerations, this uneven loading will cause a portion of the bearing race to free a ball sooner than would be the case if the misalignment did not exist. The degree of bearing performance degradation is statistical in nature but a reasonable approximation to the mean can be obtained by use of equation (4).

$$H = h_s - \alpha R_i \tag{4}$$

h = Maximum allowable axial preload deflection change without bearing brinneling.

h_s = Allowable axial preload deflection change if misalignments did not exist.

R_i = Pitch radius of the bearing.

α = Net average angular misalignment of the bearing inner race to the bearing outer race due to misalignments.

For the VRU platform the angle α can be estimated as .000233 radian. This is the average sum of the angular parallelism tolerance of .002" in ten inches (.0002 radians) and the concentricity to tolerance of .002" in approximately 7-1/2 inches (.000267 radians).

Since the average preload of 15 pounds corresponds to an axial preload deflection of about .0003 inches (h_s) equation (4) indicates a value of h:

$$h = .0003 - (.000233)(.500)$$
$$= .000184 \text{ inches}$$

This is an effective degradation of acceleration, vibration, and shock support of 25 pounds or, in effect, a decrease of maximum support from 70 pounds to 45 pounds. This is a significant reduction. To compensate for this, it would be necessary to increase the basic preload from 15 pounds to about 27 pounds (the other gimbal preloads would also be increased proportionately).

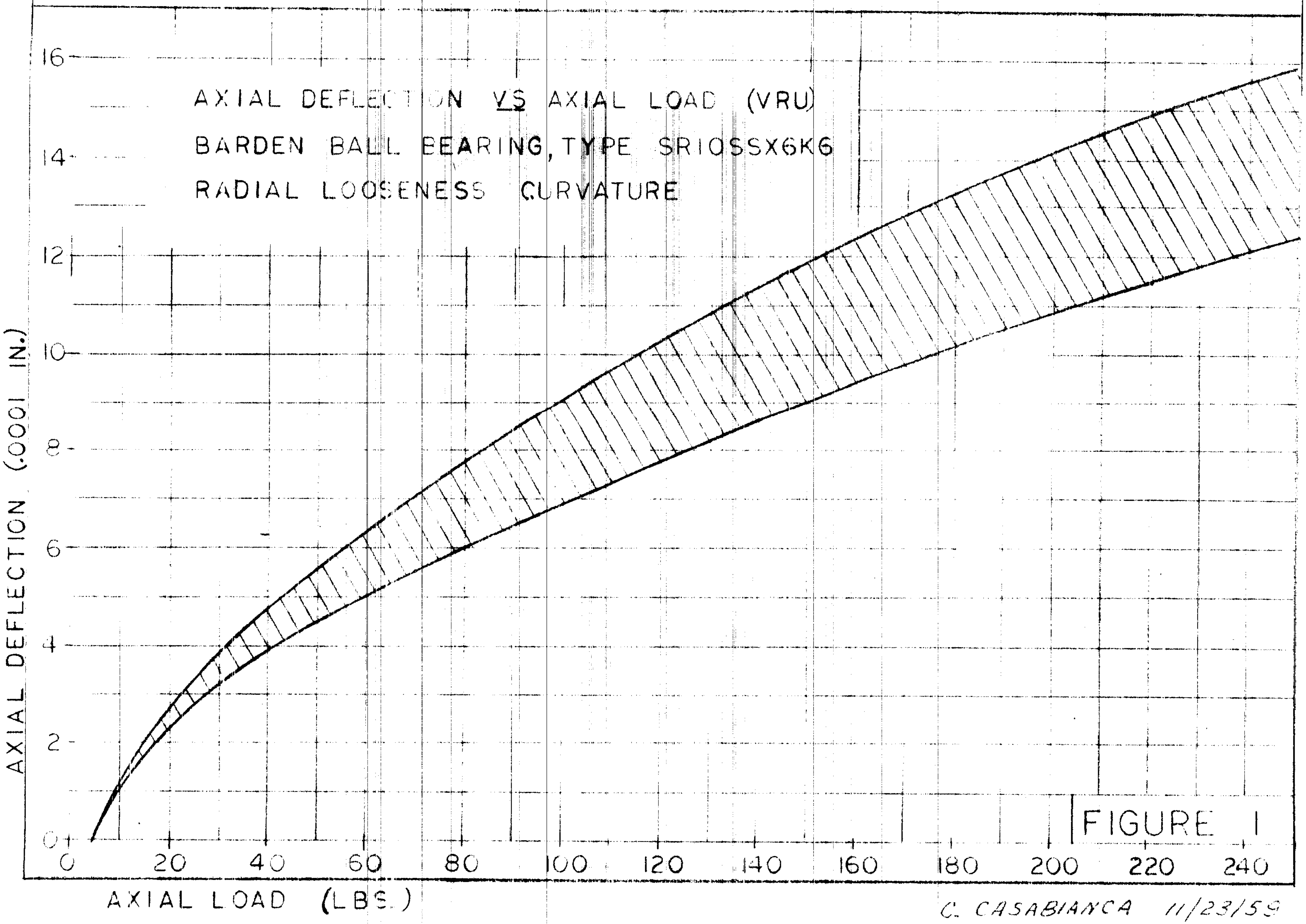


FIGURE 1

C. CASABIANCA 11/23/59

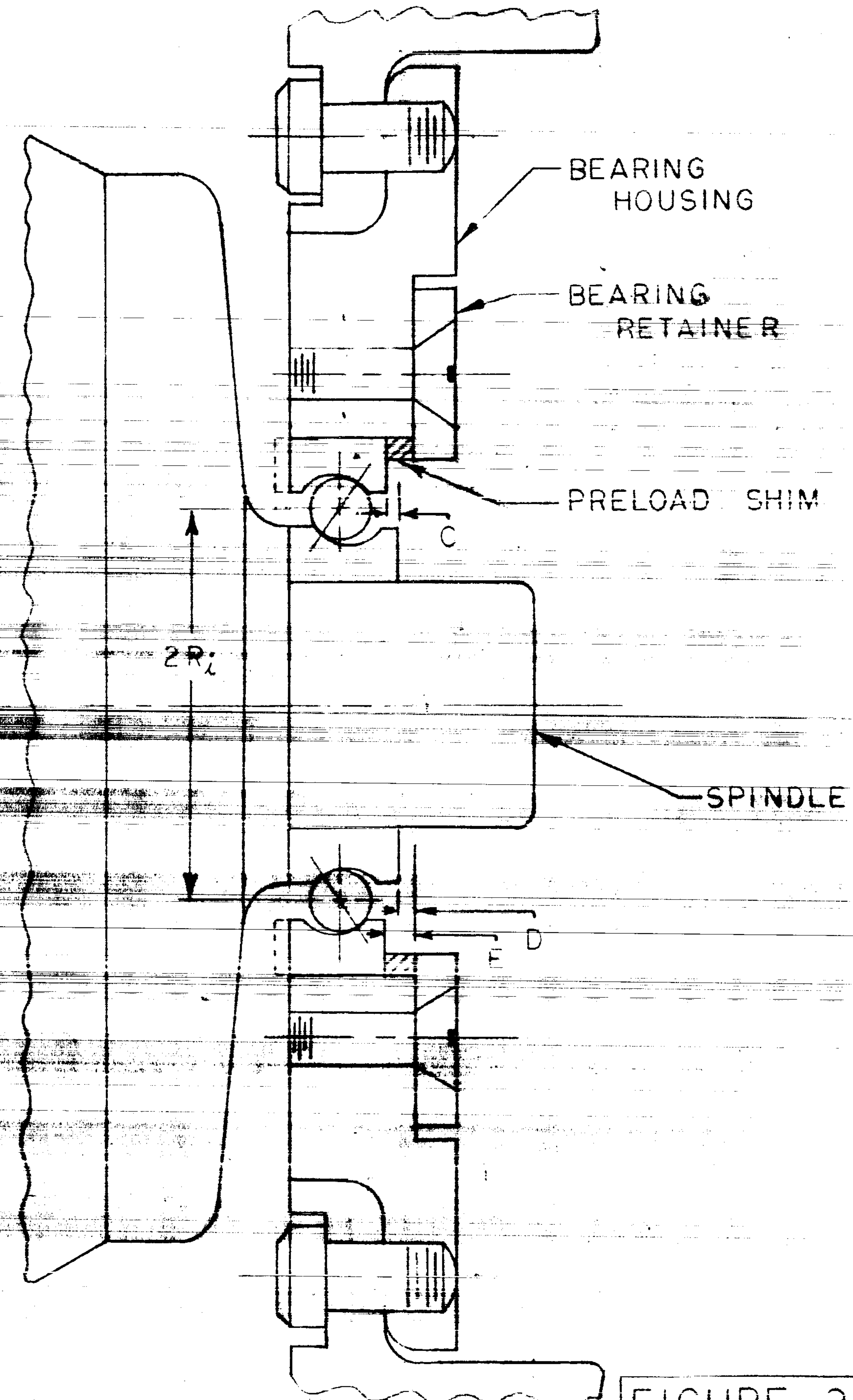

BEARING
HOUSING
BEARING
RETAINER
PRELOAD SHIM
C
$2R_i$
SPINDLE
D
E

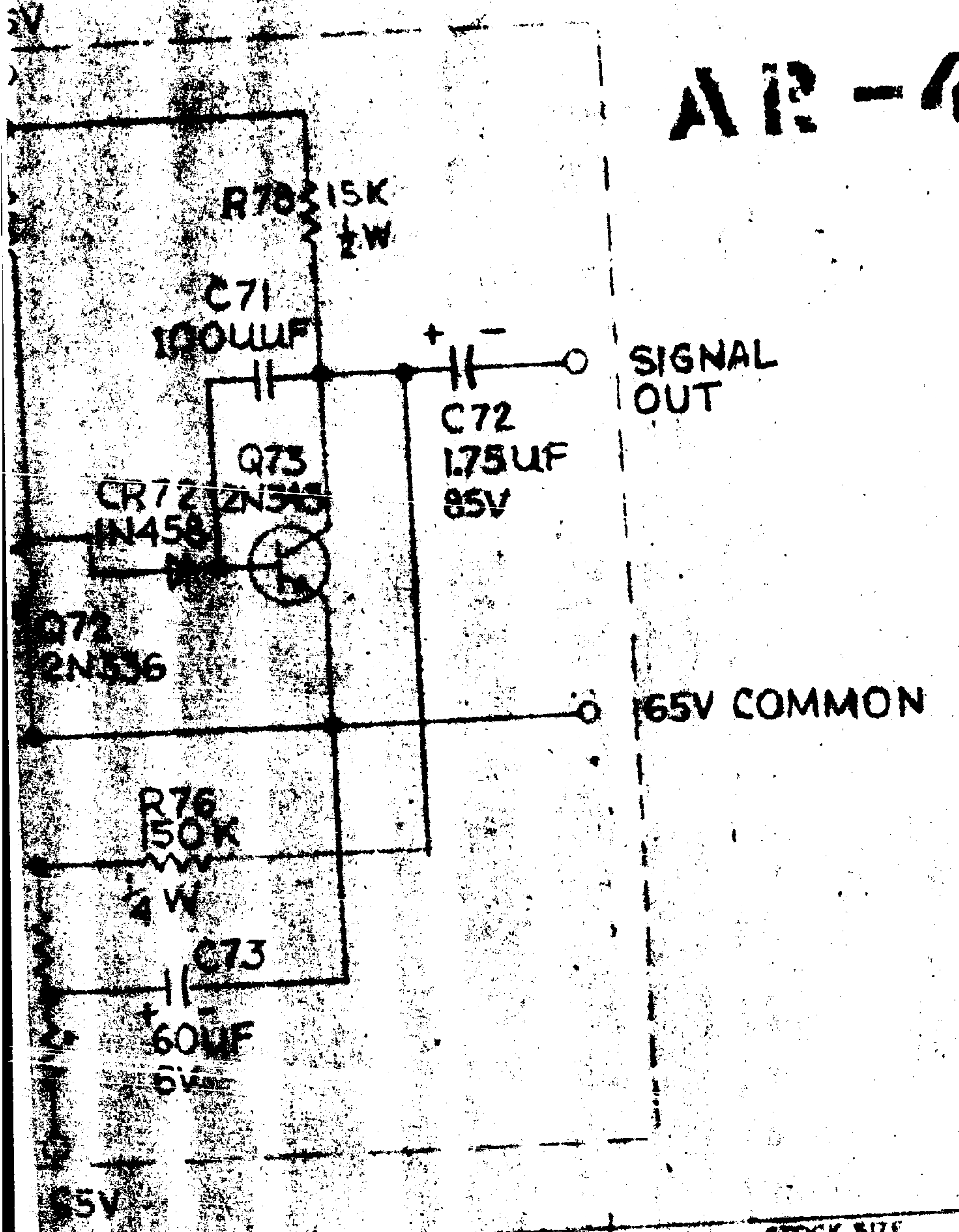
FIGURE 2

B 3162282

CHANGE DESCRIPTION

FL	RELEASE DATE	DWN	CHK	STR	MATL PROC	ENGR	DSN CHIEF

AR-4



STOCK SIZE	MATERIAL	NO. REQD	FIND NO

SPECIFICATION — REF DESIGNATION – ELEC. DWG

PRE AMPLIFIER, GYRO STABILIZATION SCHEMATIC DIAGRAM (VRU)

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY ITTL

DWG SIZE B — 3162282

REFERENCE J3162280

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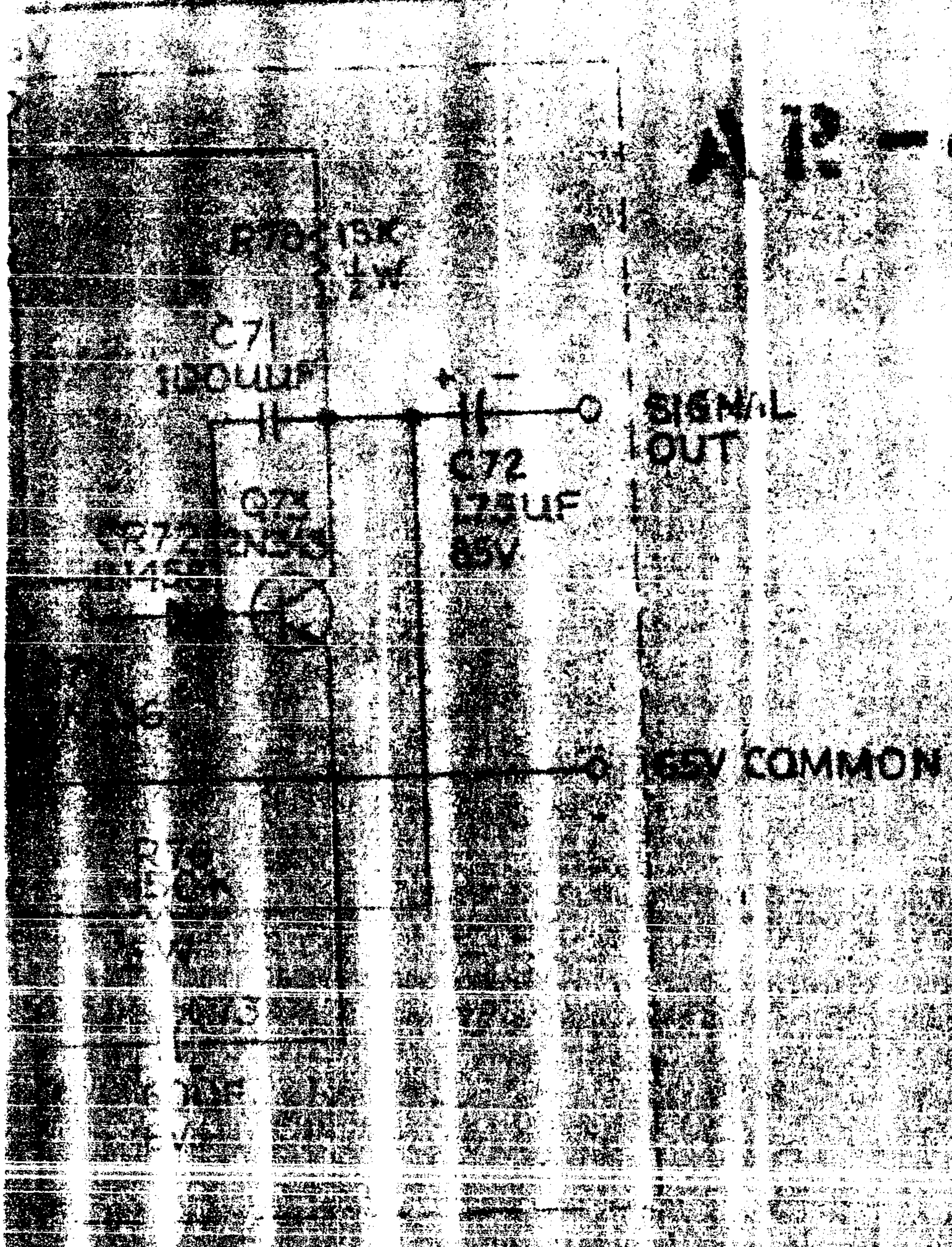

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